

Figure 10-1. Distribution of Pennsylvanian rocks at the surface (solid color) and in the subsurface (diagonal lines) (modified from Berg and others, 1980), and the location of coal fields in Pennsylvania (from Pennsylvania Geological Survey, 1992).

## CHAPTER 10 PENNSYLVANIAN

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### INTRODUCTION

The Pennsylvanian was originally named as a series within the Carboniferous System by H. S. Williams (1891) for exposures in Pennsylvania and was later raised to a system by Chamberlin and Salisbury (1905). It underlies about 35 percent of Pennsylvania, mostly in the Appalachian Plateaus physiographic province, but including important outliers elsewhere (Figure 10-1). It is probable that Pennsylvanian rocks originally covered the entire state, except in the southeastern source area. Pennsylvanian sediments were derived, principally, from southeastern orogenic highlands along the present margin of the North American plate. An important secondary source was the cratonic area to the north. Other possible sources were the Adirondack and Taconic highlands to the northeast. Pennsylvanian sedimentation took place in an elongate basin, aligned northeast to southwest, receiving sediments from all directions except the west and southwest. A rapidly subsiding geosynclinal trough to the southeast graded into an epicontinental shelf to the northwest (Figure 10-2).

Paleomagnetic studies show that Pennsylvania lay 5 to 10 degrees south of the equator during Pennsylvanian time (Scotese and others, 1979; Ross and Ross, 1985). Examination of Pennsylvanian flora by White (1913), Köppen and Wegener (1925), and Camp (1956) indicated a tropical to subtropical setting having abundant rainfall in the Early and Middle Pennsylvanian. Cecil and others (1985) have concluded that the Late Pennsylvanian was substantially more arid.

### LITHOSTRATIGRAPHY

#### General

The rocks of the Pennsylvanian System in Pennsylvania are predominantly clastic and contain subordinate amounts of coal and limestone. The Pennsylvanian reaches a maximum theoretical composite thickness of about 4,800 feet and a maximum known thickness of about 4,400 feet near Llewellyn in Schuylkill County in the Southern Anthracite field, assuming that the top of this section is not Permian.

\*Deceased.

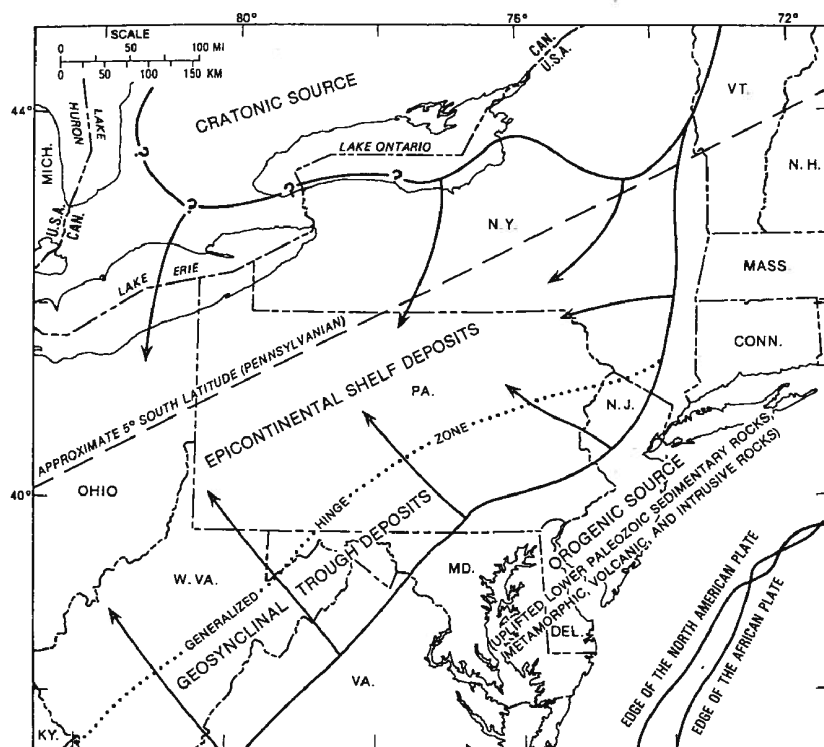


Figure 10-2. Generalized paleogeography of the Pennsylvanian depositional basin and source areas (after Edmunds and others, 1979).

In southwestern Pennsylvania, where the lower part of the system is absent, Pennsylvanian rocks are between 1,300 and 1,500 feet thick.

The bituminous coal fields of western Pennsylvania and the anthracite fields of eastern Pennsylvania each have their own stratigraphic nomenclature (Figure 10-3). The name "Pottsville" is employed in both areas, but with a different definition of the upper boundary. Nomenclature of the Broad Top and north-central areas of Pennsylvania is loosely tied to that of the western part of the state, but correlations are unclear, and each area has its own coal bed nomenclature.

The Mississippian-Pennsylvanian boundary in the Anthracite region is placed at the top of the highest red bed separating the Mauch Chunk and Pottsville Formations in the conformable and gradational sequence exposed near Pottsville, Schuylkill County (White, 1900). Rocks containing the systemic boundary are conformable throughout the Southern, Western Middle, and Eastern Middle Anthracite fields. Elsewhere in the state, the systemic boundary is disconformable, as some part of the earliest Pennsylvanian is absent (Figure 10-3).

The exact placement of the Pennsylvanian-Permian boundary is a complex and controversial problem that is discussed in Chapter 11. Conventionally, it is placed

at the bottom of the Waynesburg coal bed.

Other than the base of the system, all principal stratigraphic subdivisions are defined using key-bed boundaries, mostly coals or their underclays. Many of these key beds lack continuity or lithologic distinctiveness. Therefore, interval and sequence are important factors in keeping track of various unit boundaries.

Except for the dominant sandstone and conglomerate composition of the Pottsville and Llewellyn Formations, there is no preponderant lithologic distinctiveness in any of the other major Pennsylvanian stratigraphic units. All are a more-or-less heterogeneous mixture of interbedded sandstones, siltstones, shales, claystones, limestones, and coals. Differences that do exist among the various parts of the section reflect the presence, absence, or variation in proportion of some lithologies

or secondary characteristics (Figure 10-4).

The areal extent of individual lithosomes varies enormously, and none is known to be completely persistent. Individual lithosomes rarely exceed several tens of feet in thickness, although what are believed to be stacked sandstones may exceed a few hundred feet. Vertical and lateral gradation and interfingering among lithologies are very common. In western Pennsylvania alone, more than 100 individual lithosomes have been named, and many others are unnamed. In a general way, the various lithologies tend to be arranged in cycles that represent fluctuations between low-energy deposition (e.g., coals and limestones) and high-energy deposition (e.g., sandstones and conglomerates). Because the composition and order of lithologic sequences reflect such a wide variety of depositional settings, however, it is impossible to denote lithologic cycles or cyclothems in any concise, meaningful way.

### Pottsville Formation of Western Pennsylvania

The Pottsville Formation in western Pennsylvania ranges from 20 to at least 250 feet in thickness. Its basal contact is apparently everywhere disconformable and from south to north overlies increas-

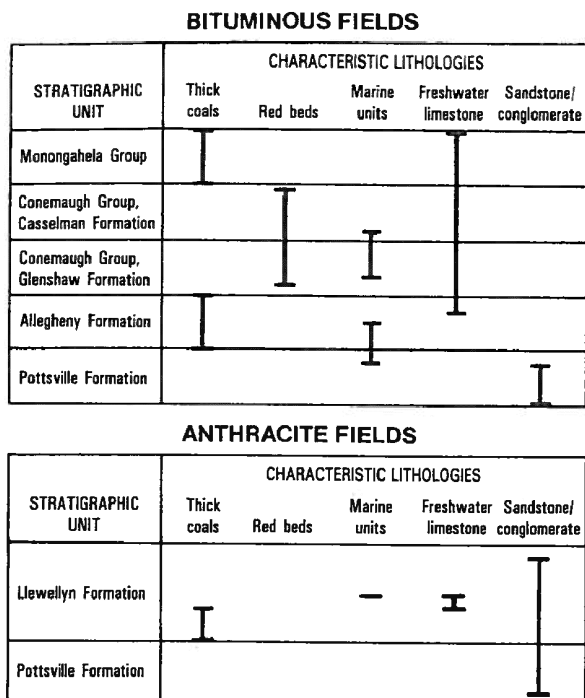
PERMIAN	GLOBAL		NORTH AMERICAN		FLORAL ZONE (Read and Mamay, 1964)	EAST-CENTRAL PENNSYLVANIA	NORTH- EASTERN PENNSYLVANIA	NORTH- CENTRAL PENNSYLVANIA	NORTH- WESTERN PENNSYLVANIA	SOUTH- WESTERN PENNSYLVANIA	SOUTH- CENTRAL PENNSYLVANIA (BROAD TOP FIELD)
	"SERIES"	STAGE	SERIES	STAGE							
PENNSYLVANIAN	Lower	Assel- ian	Wolf- campian		13					Dunkard Gp.	
	Silesian	Stephanian	Upper Pennsylvanian	Virgilian	?	?	?			?	
					12	~~~~~?~~~~~	~~~~~?~~~~~			Monongahela Gp.	
					?						
					11	Llewellyn Fm.	Llewellyn Fm.		~~~~~	Casselman Fm.	~~~~~
					?				Conemaugh Gp.		
				Missourian					Glenshaw Fm.	Glenshaw Fm.	Conemaugh Gp. and Allegheny Fm., undivided
					10			Allegheny Fm.	Allegheny Fm.	Allegheny Fm.	
		Westphalian	Middle Pennsylvanian	Desmoinesian				~~~~~			
					9	Sharp Mountain Mbr.	Sharp Mountain Mbr.	Pottsville Fm.	Pottsville Fm.	Pottsville Fm.	?
					8	Pottsville Fm.	Pottsville Fm.	?			Pottsville Fm.
					7		Campbells Ledge Sh.				
	Namurian	Lower Pennsylvanian	Morrowan	Atokan	6	Pottsville Fm.					
					5	Schuykill Mbr.					
					4	Tumbling Run Mbr.					
						Neuch Chunk Fm.					

Figure 10-3. Correlation chart of Pennsylvanian stratigraphic units and floral zones (modified from Edmunds, 1993, Figure 4, p. 16, and Read and Mamay, 1964).

ingly older Mississippian and possibly uppermost Devonian rocks (Figure 10-5).

The base of the Brookville coal marks the upper boundary of the Pottsville Formation. The Pottsville (formerly a group) was divided into the Sharon, Connoquenessing, Mercer, and Homewood Formations,

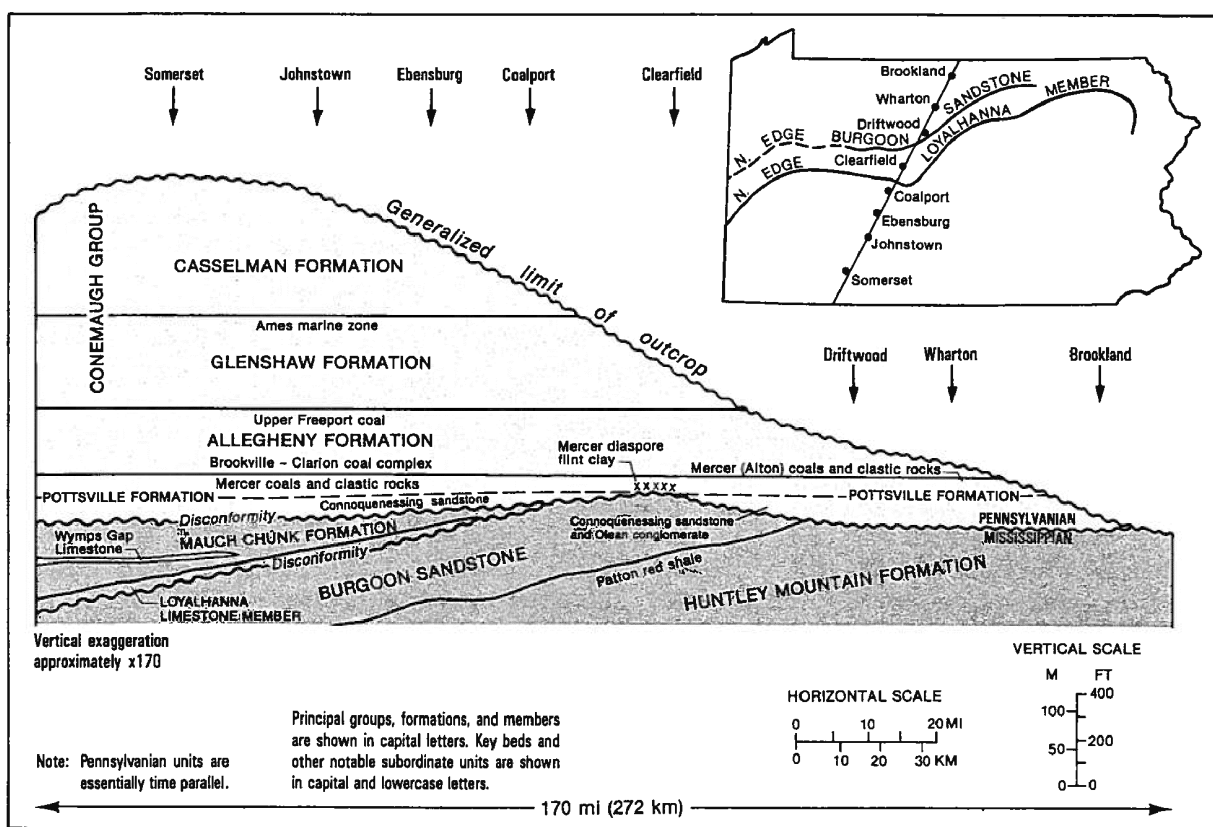
in ascending order (Carswell and Bennett, 1963; Poth, 1963). It has proven to be very difficult to consistently apply this breakdown of the Pottsville beyond the area where it was originally established (Mercer County and parts of adjacent counties). In practice, the western Pottsville is usually divided into an upper



**Figure 10-4.** Stratigraphic distribution of definitive lithologic characteristics of the Pennsylvanian units in Pennsylvania.

sequence consisting of the Mercer coals and associated and overlying rocks, and a lower sequence dominated by sandstones (Figure 10-6).

In some places, the Pottsville is particularly thin, mainly because of depositional overlap with sequential loss of the basal elements of the group but partly because of the thinning or absence of internal units. Both cases are believed to reflect trends in the topographic relief of the pre-Pottsville erosion surface. A particularly important topographic feature of this erosion surface is the long, cuestaslike ridge (or ridges) corresponding to the outcrop of the Mississippian Burgoon Sandstone and similar prominent sandstones near the base of the overlying Mauch Chunk Formation (Edmunds and Berg, 1971). This erosional high extends from at least as far east as



**Figure 10-5.** Generalized stratigraphic cross section of Pennsylvanian rocks from Somerset County to Potter County (modified from Edmunds and others, 1979).

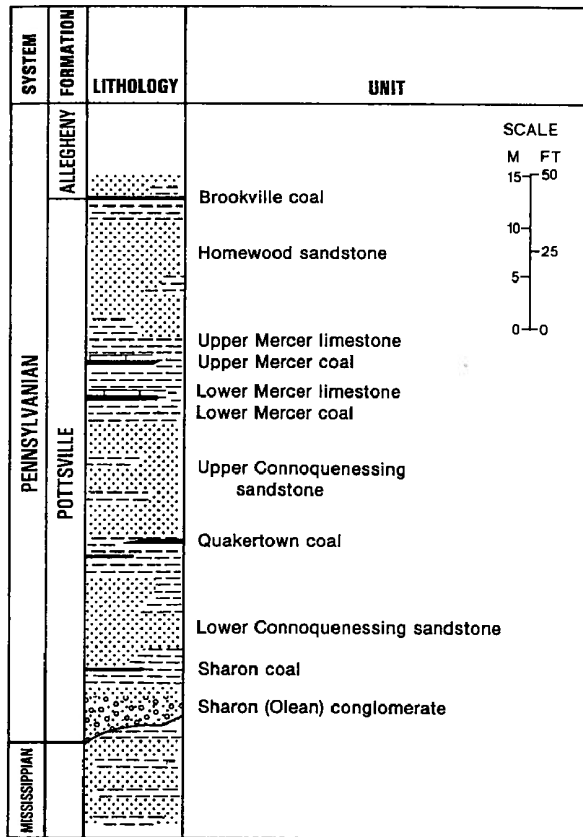


Figure 10-6. Generalized stratigraphic section of the Pottsville Formation of western Pennsylvania.

Clinton County across Centre and Clearfield Counties, and possibly west from there in the subsurface to connect with the "cuesta of Mississippian limestones" described by Wanless (1975) in eastern Ohio. The pre-Mercer Pottsville is missing along the ridge crests because of nondeposition. Thus, the pre-Mercer Pottsville is effectively separated into a northern sequence with a northern source and a southern sequence with a southeastern source, each largely isolated from and independent of the other (Figures 10-5 and 10-18C). It is along topographic highs that the unusual Mercer high-alumina hard clay formed as an apparent residual weathering product (Edmunds and Berg, 1971).

The pre-Mercer Pottsville, in both its northern and southern areas of occurrence, is dominantly sandstone and conglomeratic sandstone. Intervals of siltstone, shale, and thin coal are not uncommon and, in places, considerable parts of the section grade laterally into finer clastics. The pre-Mercer Pottsville is commonly divided into the upper and lower Connoquenessing sandstones, which are separated by a

shaly interval that includes the Quakertown coal (Figure 10-6). In northwestern Pennsylvania, the Connoquenessing sandstones are underlain by the Sharon coal and shale and the basal Sharon conglomerate, which are mostly confined to drainage channels cut into the pre-Pennsylvanian erosion surface. Farther east, the Olean conglomerate occurs at the same level. Meckel (1964, 1967) considered the Sharon and Olean to be separate, but contemporaneous, sediment lobes that were built from a northern source. There do not appear to be any clear equivalents to the Sharon and Olean in southwestern Pennsylvania.

In Pennsylvania, the pre-Mercer Pottsville is entirely nonmarine. Its thickness varies from 0 to as much as 175 feet. Recognition of the unconformable base of the Pottsville is often a problem, even in good exposures, because of the difficulty in separating Pottsville sandstones from those of the underlying Mauch Chunk, Burgoon, Shenango, and other formations.

The upper part of the Pottsville Formation, commencing with the lowest Mercer coal or its underclay, is a very complex, highly variable sequence between 20 and approximately 80 feet thick. It can contain several coals with intervening shales, underclays, and other clastics, and in Mercer and adjacent counties, it contains two marine limestones. Shales containing marine or brackish-water fauna occur widely, if irregularly, throughout western Pennsylvania. The upper part of the interval commonly contains one or more well-developed sandstones, which can displace many or all of the lower units.

### Allegheny Formation

The Allegheny Formation includes those rocks from the base of the Brookville coal to the top of the Upper Freeport coal (Figure 10-7). It was specifically defined to include all of the economically significant coals present in that part of the Pennsylvanian sequence. The thickness of the formation is between 270 and 330 feet in Pennsylvania, and there is no obvious regional trend. The Allegheny Formation is a complex, repeating succession of coal, limestone, and clastics, ranging from claystone or underclay to coarse sandstone. A typical depositional cycle includes, in ascending order, coal, shale (marine or nonmarine), sandstone, and underclay (some with associated nonmarine limestone), but many variations occur. Interfingering and lateral gradation among the various lithologies are very common. No individual bed or lithosome is universally persistent, but some coals, marine shales, and limestones seem to be fairly continuous over thousands of square miles. The group

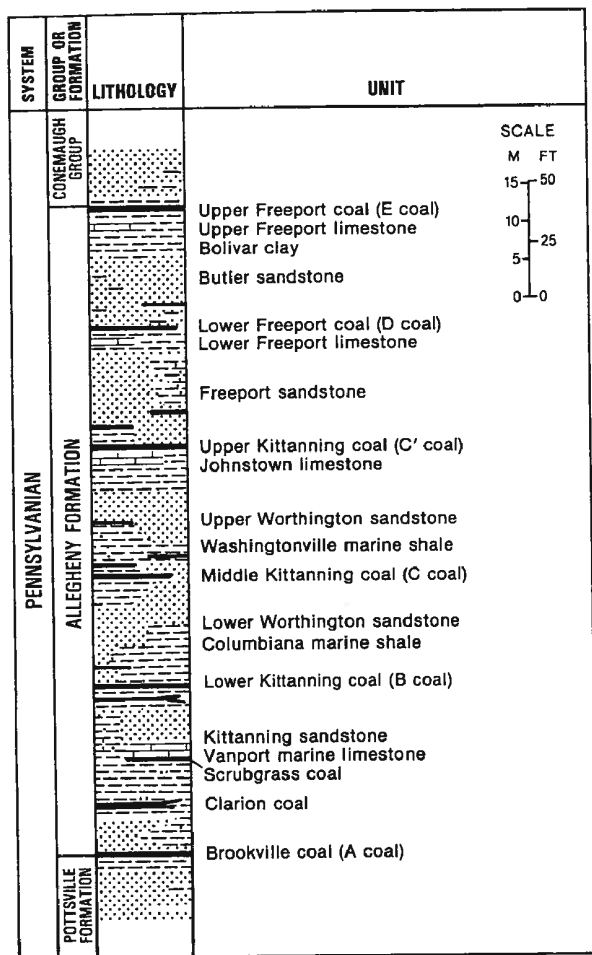


Figure 10-7. Generalized stratigraphic section of the Allegheny Formation of western Pennsylvania.

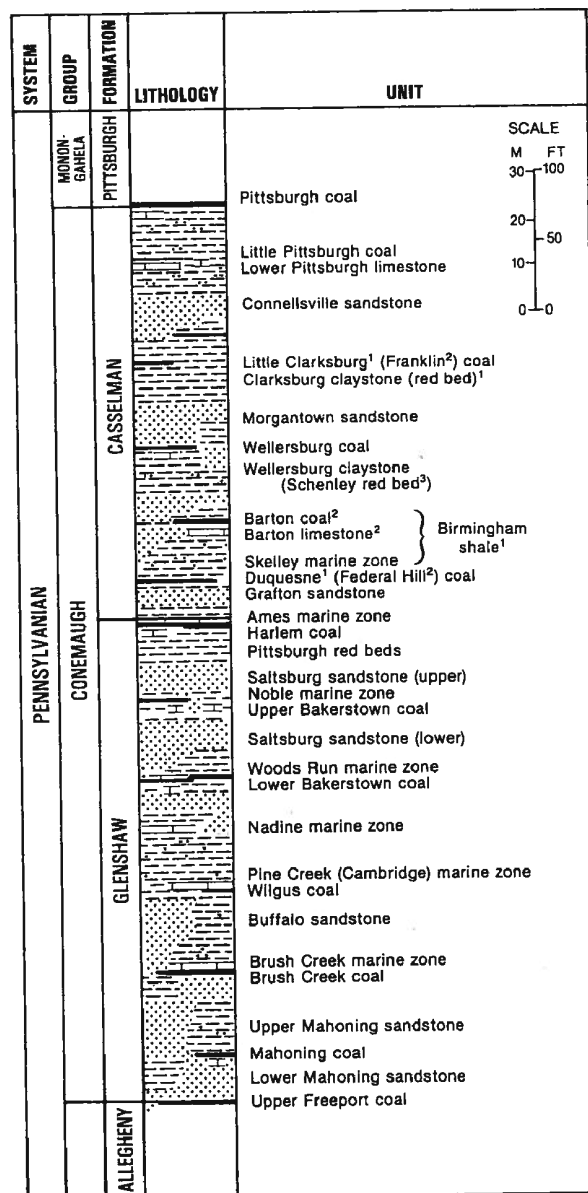
is fairly uniform in its lithologic diversity, except that marine units occur only below the Upper Kittanning underclay and, with minor exceptions, nonmarine limestones occur only at or above that unit (Figure 10-4). The Allegheny Formation contains six major coal zones. The coal in each zone may exist as a single, more-or-less continuous sheet, as a group of closely related individual lenses, or as a multiple-bed complex in which the various beds can be separated by tens of feet or merge into a single thick coal (see Chapter 37 for a discussion of individual coals).

### Conemaugh Group

#### General

The Conemaugh Group is present at the surface throughout much of southwestern Pennsylvania. A few small, isolated outliers extend as far north as Elk County. The middle part of the Llewellyn

Formation of the Anthracite region of eastern Pennsylvania is stratigraphically equivalent to the Conemaugh. This group is stratigraphically defined as the rocks lying between the Upper Freeport coal horizon and the Pittsburgh coal (Figure 10-8). The thickness of this interval ranges from 520 feet in western Washington County to 890 feet in southern Somerset County. A gradual eastward thickening of the Conemaugh is apparent.



<sup>1</sup> Name used in Pittsburgh area and southwestern Pennsylvania excluding Somerset County.

<sup>2</sup> Name used exclusively in Somerset County.

<sup>3</sup> Name used exclusively in Pittsburgh area.

Figure 10-8. Generalized stratigraphic section of the Conemaugh Group of western Pennsylvania.

Flint (1965) subdivided the Conemaugh Group into a lower formation, the Glenshaw, containing several widespread marine units, and an upper formation, the Casselman, devoid of marine units except for the Skelley, which is of limited extent. The top of the marine Ames limestone was established as the boundary between the two formations. The Ames limestone is commonly present within a persistent marine zone that is traceable over much of the Appalachian Plateaus province.

In gross lithologic aspect, the Conemaugh is a clastic sequence dominated by siltstone, claystone, shale, and sandstone. In much of the section, primary bedding and other sedimentary structures have been destroyed by rootworking, bioturbation, and desiccation.

Calcareous and sideritic mineralization, in the form of nodules and fracture fillings, is commonly present. Iron-oxide-rich red beds and red and green mottled beds occur throughout the Conemaugh section. Most of these are caliche paleosols formed in an alternating wet-dry semiarid climate. Characteristic features include lack of bedding, hackly fracture, calcareous cutans, and small calcareous nodules. A few red beds situated in marine zones have undisturbed bedding and contain marine fossils. The red coloration in these beds is not a product of in-place soil formation but resulted from deposition of originally red detritus. Even though these beds are variable in thickness and laterally nonpersistent, some of them, especially those in the Glenshaw, roughly maintain their stratigraphic position. Coals in the Conemaugh, with local exceptions, are generally sparse, thin, and economically unimportant. Conemaugh underclays are generally impure, silty to sandy clay zones containing nodular freshwater limestone. Bedded limestones occur in some underclay zones and increase in abundance and thickness upward. The best development of the limestones is near the top of the group.

### Glenshaw Formation

The thickness of the Glenshaw Formation ranges from a minimum of 280 feet in extreme western Pennsylvania to a maximum of 400 to 420 feet in Somerset County and

southern Cambria County. The distinguishing feature of the Glenshaw Formation is the presence of several widespread marine units. The best developed of these, in upward succession, are the Brush Creek, Pine Creek, Woods Run, and Ames. These marine zones have both a limestone and a shale facies. The Brush Creek and Woods Run are always associated with a dark shale. The Pine Creek and Ames marine zones have a variety of lithofacies (Figure 10-9), including dark shales containing plant debris, gray-green crinoidal limestone, and red shales containing abundant and diverse marine fauna. A less prominent unit present in the Glenshaw is the Noble marine zone. This is a restricted marine to brackish shale overlying the Upper Bakerstown coal. Two other obscure Glenshaw marine zones, the Carnahan Run and the Nadine, have been reported in Pennsylvania. The Carnahan Run lies a few feet above the Woods Run limestone and appears to be of very local extent. It is separated from the Woods Run by dark fissile shale and is most likely a part of the Woods Run marine zone. The Nadine has a spotty occurrence over a much larger area, encompassing several counties. It lies a short distance below the Woods Run and is separated from it by the Lower Bakerstown coal. It is approximately 30 feet above the Pine Creek marine zone. The Nadine may be a poorly recognized, but discrete, marine zone. A zone of brackish-water fossils was found above the Mahoning coal in core from a hole drilled in 1981 by the Pennsylvania Geological Survey near Bakersville, Somerset County, and in another privately drilled hole near Blairsville, Indiana County, examined by Survey geologists in 1990. More work is needed to determine the nature and extent of this zone regionally; however, its presence suggests that there may be a

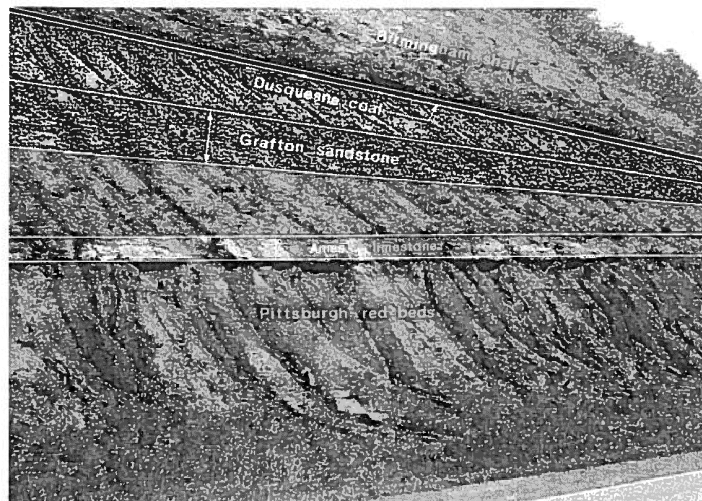


Figure 10-9. Ames limestone and associated strata of the Conemaugh Group along Pa. Route 28 near Creighton, Allegheny County. The Ames is about 3 feet thick here.



total of seven separate marine zones in the Glenshaw Formation.

### *Casselman Formation*

The thickness of the Casselman Formation ranges from 230 feet in the extreme western part of the Appalachian Plateaus province to 485 feet in southern Somerset County. The lower part of the formation maintains the marine character of the underlying Glenshaw Formation. Marine fossils have been found in a shale overlying a thin coal 30 to 60 feet above the Ames marine zone. This marine zone covers an area from Somerset County, where it is present as a shale overlying the Federal Hill coal and containing a restricted marine to brackish fauna, to Pittsburgh, where it is represented by the distinctly marine Birmingham shale, which overlies the Duquesne coal (Raymond, 1911), to the Ohio border, where it is correlative with the Skelley Limestone of Ohio. This zone represents the last marine pulse of the Paleozoic in Pennsylvania.

The Casselman rocks above the Skelley marine zone are exclusively freshwater deposits, consisting of claystone, limestone, sandstone, shale, and coal. Much of this section is occupied by massive, impure, silty to sandy, commonly calcareous claystone of various colors, ranging from gray to dull red and pale green. Regionally, the red beds are discontinuous. Red beds are scattered throughout the formation along the western state border and make up a large percentage of the section. Eastward, they become thinner and fewer in number. This trend continues into eastern Somerset and Cambria Counties, where large areas of the Casselman Formation are completely devoid of red beds. Conversely, coals are nearly absent or very thin in the west but increase in quantity eastward. In Somerset County, a few coals are thick enough to mine. Sandy shales and sandstones are also more abundant eastward. The large lateral change in the overall thickness of the Casselman Formation and in its lithologic character makes correlation of individual units within it very difficult. The Casselman is also one of the least studied formations of the Pennsylvanian because of its lack of economically important rocks and paleontologically significant fossil zones. As a result, the stratigraphic nomenclature used in the literature is very confusing regionally and is only reliable locally.

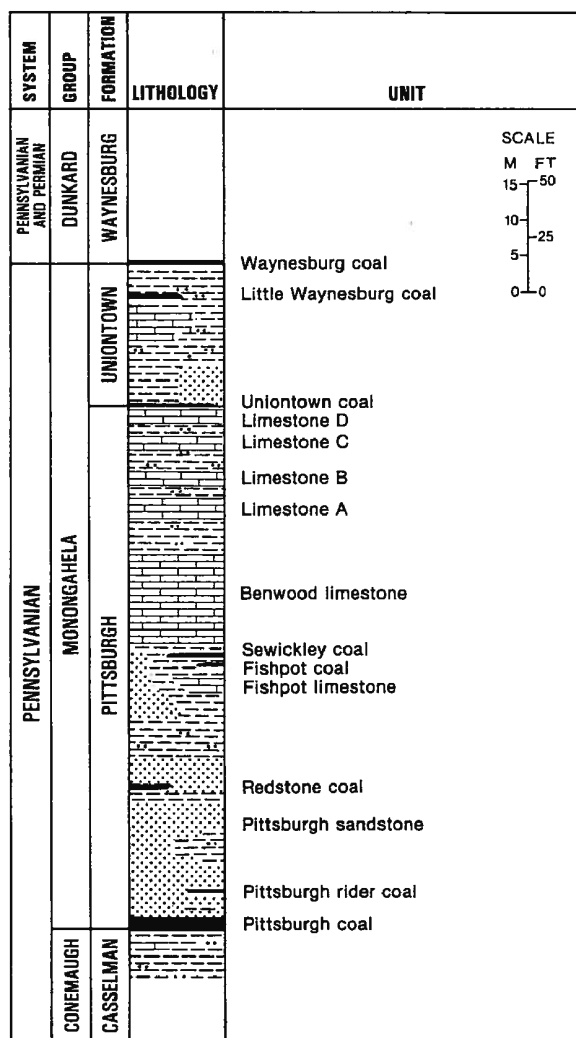
### **Monongahela Group**

The Monongahela Group extends from the base of the Pittsburgh coal to the base of the Waynesburg coal (Figure 10-10). It is divided into the Pittsburgh and Uniontown Formations at the base of the Union-

town coal. The group is about 270 to 400 feet thick in Pennsylvania, increasing in thickness irregularly from the western edge of the state to western Fayette County. It reportedly thins somewhat from there eastward to the Uniontown area in central Fayette County (Hickok and Moyer, 1940, p. 100). It is entirely nonmarine.

The Monongahela Group is a sedimentary sequence dominated by limestones and dolomitic limestones, calcareous mudstones, shales, and thin-bedded siltstones and laminites, all of which were deposited in a relatively low energy environment. Several coal beds are present.

The upper one half to two thirds of the Pittsburgh Formation consists principally of flat-lying, inter-



**Figure 10-10.** Generalized stratigraphic section of the Monongahela Group of western Pennsylvania.

layered limestones and calcareous mudstones, and relatively little coarse clastic rock (Figure 10-11). The only sandstone of significant thickness within the formation lies directly above the Pittsburgh coal complex. A major fluvial channel system, flowing north to northwest through what is now Greene and Washington Counties, deposited an elongate sandstone body up to 80 feet thick and several miles wide (Figure 10-12). To the west of this sandstone, the entire section is composed mostly of limestone and calcareous claystone. Eastward over a large area, the sandstone grades into a shale containing some thin, discontinuous sandstone bodies.

The Uniontown Formation consists mostly of thin-bedded sandstones and some channel-fill sandstones. It also contains siltstones and shales that may grade laterally into bedded limestones or cherty limestone.

Coals make up only a small part of the total Monongahela Group, but include, at the base, the Pittsburgh coal, which is generally 4 to 10 feet thick and unique in its areal continuity. Other coals can be locally thick, but lack lateral persistence (see Chapter 37 for a discussion of individual coals).

### Pottsville Formation of the Anthracite Area

The Pottsville Formation of the anthracite fields of northeastern and east-central Pennsylvania (Figure 10-13) extends from the top of the highest red bed of the Mauch Chunk Formation, where the contact is conformable in the Southern and Middle Anthracite fields, to the base of the Buck Mountain (Red Ash) coal or its underlying shale (White, 1900; Wood and others, 1956). The top of the Pottsville Formation in eastern Pennsylvania and the top of the Pottsville in western Pennsylvania are not equivalent in that the Buck Mountain coal is generally correlated with the Lower Kittanning coal rather than the Brookville coal, which is the upper boundary in

the west (see Figure 10-7). The Pottsville is divided, in ascending order, into the Tumbling Run, Schuylkill, and Sharp Mountain Members (Wood and others, 1956).

The thickness of the Pottsville Formation ranges from a maximum of about 1,600 feet in the Southern Anthracite field to less than 100 feet in the Northern Anthracite field (Meckel, 1964; Wood and others, 1969). This northeastward thinning reflects the loss of the Tumbling Run and Schuylkill Members, which reach a maximum thickness of 600 and 700 feet, respectively, in the Southern field, but are absent in the Northern field, where the Sharp Mountain Member rests disconformably on Mississippian through Upper Devonian rocks (Figures 10-14 and 10-15). C. B. Read (Moore and others, 1944) concluded that there is a major disconformity between the Sharp Mountain Member and all underlying rocks, including the Schuylkill and Tumbling Run Members, throughout the entire Anthracite region (see also Edmunds, 1988; Inners, 1988). Wood and others (1969) and Meckel (1964) rejected the presence of this disconformity between the Sharp Mountain and Schuylkill Members in the Southern and Middle fields; they considered the loss of the Schuylkill and Tumbling Run Members to be a matter of depositional thinning and facies loss of the lower part of the Tumbling Run to the Mauch Chunk Formation.

The Pottsville Formation is approximately 50 to 60 percent cobble and pebble conglomerate and conglomeratic sandstone, 25 to 40 percent sandstone, and 10 to 20 percent finer clastics and coal. Most of the formation consists of fining-upward alluvial cycles. Pottsville rocks are mostly light gray to black, except the lower two thirds of the Tumbling Run,

**Figure 10-11.** Benwood and Fishpot limestones of the Pittsburgh Formation along Interstate Route 79 near Heidelberg, Allegheny County. The roadcut is approximately 100 feet high. See also Figure 12 in the color section.



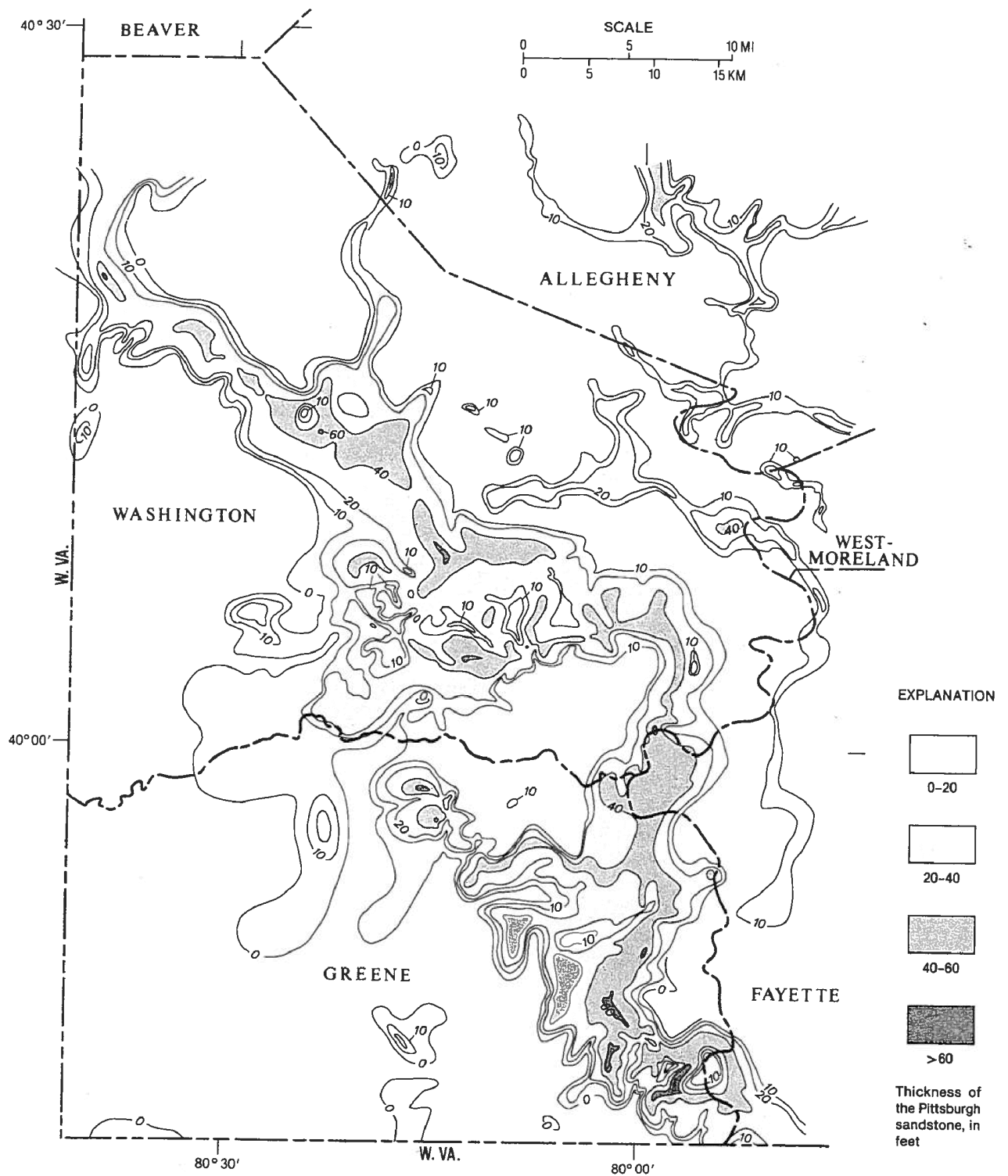


Figure 10-12. Isopach map of the Pittsburgh sandstone of the Pittsburgh Formation (from Roen and Kreimeyer, 1973). This channel deposit is from a major river that flowed generally northwest.

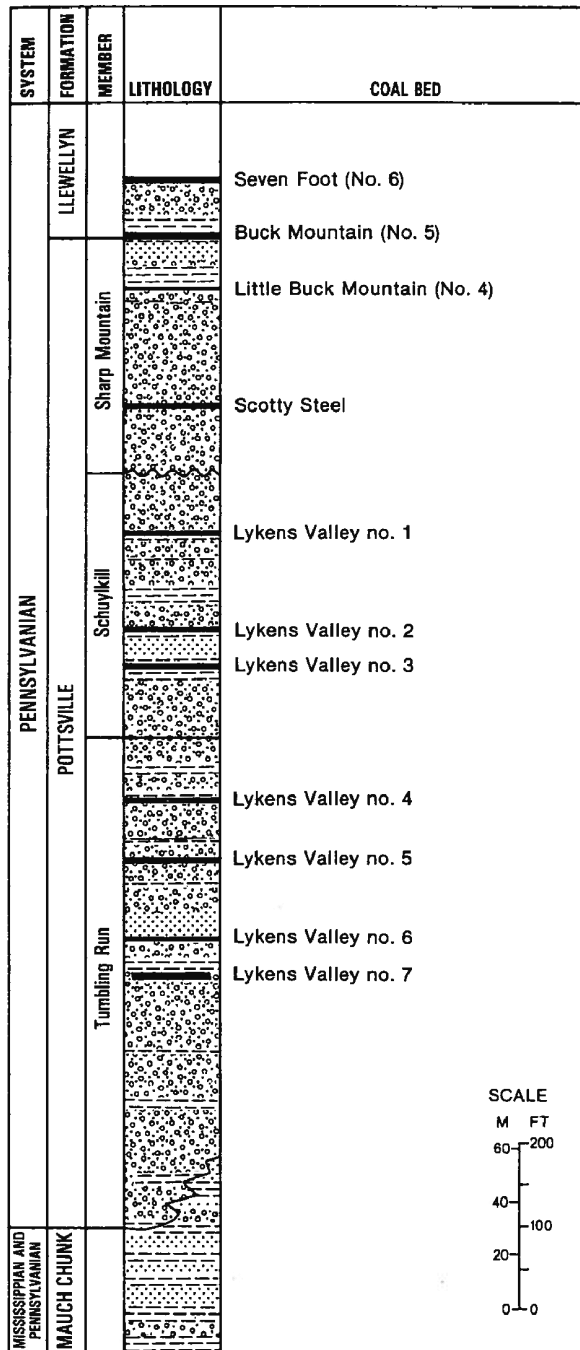


Figure 10-13. Generalized stratigraphic section of the Pottsville Formation in the Anthracite region of Pennsylvania.

which is olive to greenish gray. Fourteen coal beds have been named, but most are relatively discontinuous, and only a few persist outside the Southern field. The Pottsville is entirely nonmarine.

## Llewellyn Formation

The Llewellyn Formation includes all remaining rocks in the Anthracite region above the base of the Buck Mountain (Red Ash) coal or the underlying shale (Figures 10-16 and 10-17). The greatest thickness of preserved section is about 3,500 feet. Lithologically, the Llewellyn is a complex, heterogeneous sequence of subgraywacke clastics, ranging from conglomerates to clay shale and containing numerous coal beds. Conglomerates and sandstones dominate. There are also a few thin, nonmarine limestones and, in the Northern Anthracite field, the marine Mill Creek limestone bed. Rapid lateral and vertical lithologic variability is characteristic throughout the Llewellyn.

The Llewellyn contains 40 coal beds that have sufficient persistence or minability to be named, plus numerous unnamed local coals and splits. The thickest and most persistent coals are confined to the lower 1,500 feet, and most of them occur in the lower 650 feet of the formation (see also Chapter 36). The maximum natural thickness of the coal beds generally does not exceed 50 to 60 feet, although in complex structural situations, where beds are folded back upon themselves or mass flow has occurred, thicknesses of 100 feet or more may occur.

## PALEONTOLOGY AND BIOSTRATIGRAPHY

Because plants are the only fossil forms present in reasonable abundance throughout the stratigraphic and geographic extent of the Pennsylvanian System within Pennsylvania, paleobotany is the method used for general correlations. Early work produced large amounts of taxonomic data (Lesquereux, 1879, 1880, 1884) and limited correlation of certain beds and intervals (White, 1900, 1904), but it was not until the work of Darrah (1937, 1969) on the post-Pottsville and Read (Moore and others, 1944; Read and Mamay, 1964) on the entire Pennsylvanian that all-inclusive paleobotanical zonation was established (Figure 10-3). Gillespie and Pfefferkorn (1979) further refined the paleobotanical zonation of the Pennsylvanian standard section in West Virginia, work that should be applicable to the section in Pennsylvania as well.

The absence of Lower Pennsylvanian floral zones (zones 4, 5, and, in many places, 6), coupled with the loss of Mississippian floral zones, led White (1904) to recognize the widespread disconformity at the base of the Pennsylvanian throughout Pennsylvania, except in the Southern and Middle Anthracite fields (Figure 10-3). The apparent absence of Atokan-age flo-

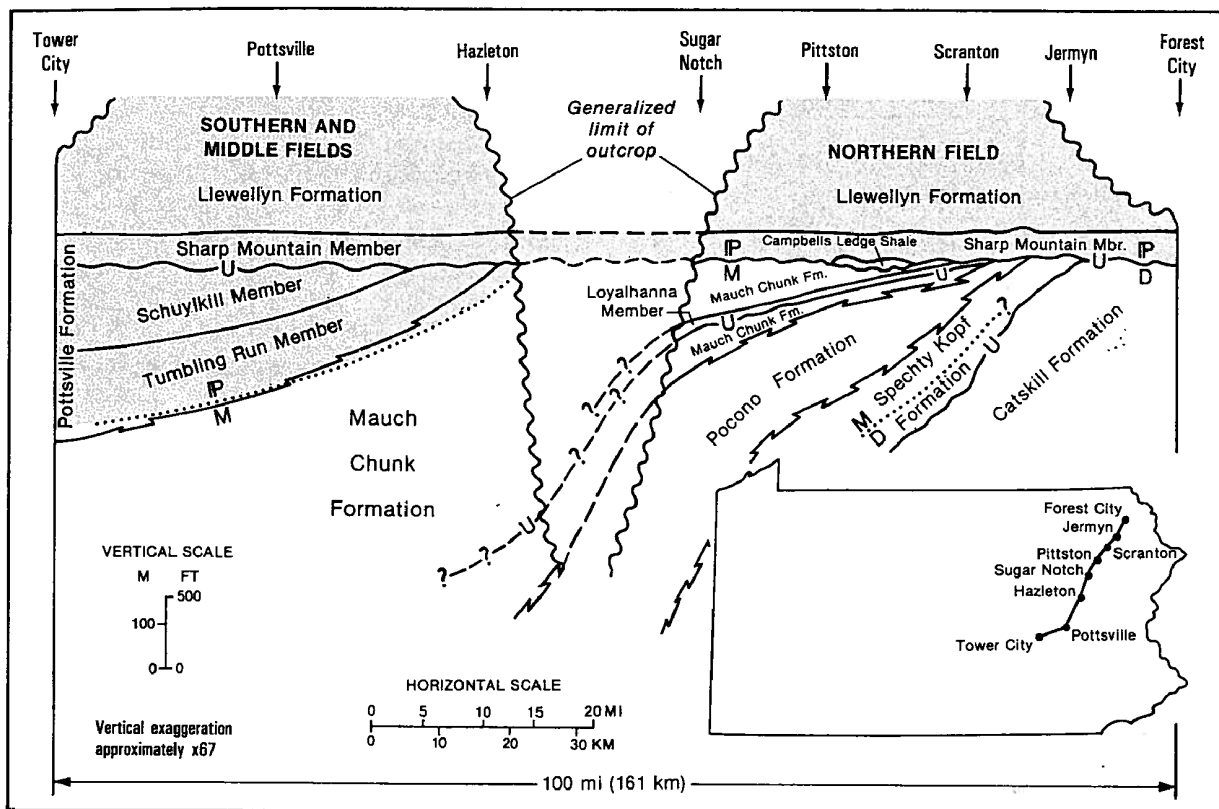


Figure 10-14. Generalized stratigraphic cross section of Pennsylvanian rocks from Tower City, Schuylkill County, to Forest City, Susquehanna County (from Edmunds, 1988).

ral zones (zones 7 and 8) in the Southern and Middle Anthracite fields indicated to Read (Moore and others, 1944) a major disconformity between the Sharp Mountain and the underlying Schuylkill and Tumbling Run Members of the Pottsville Formation.

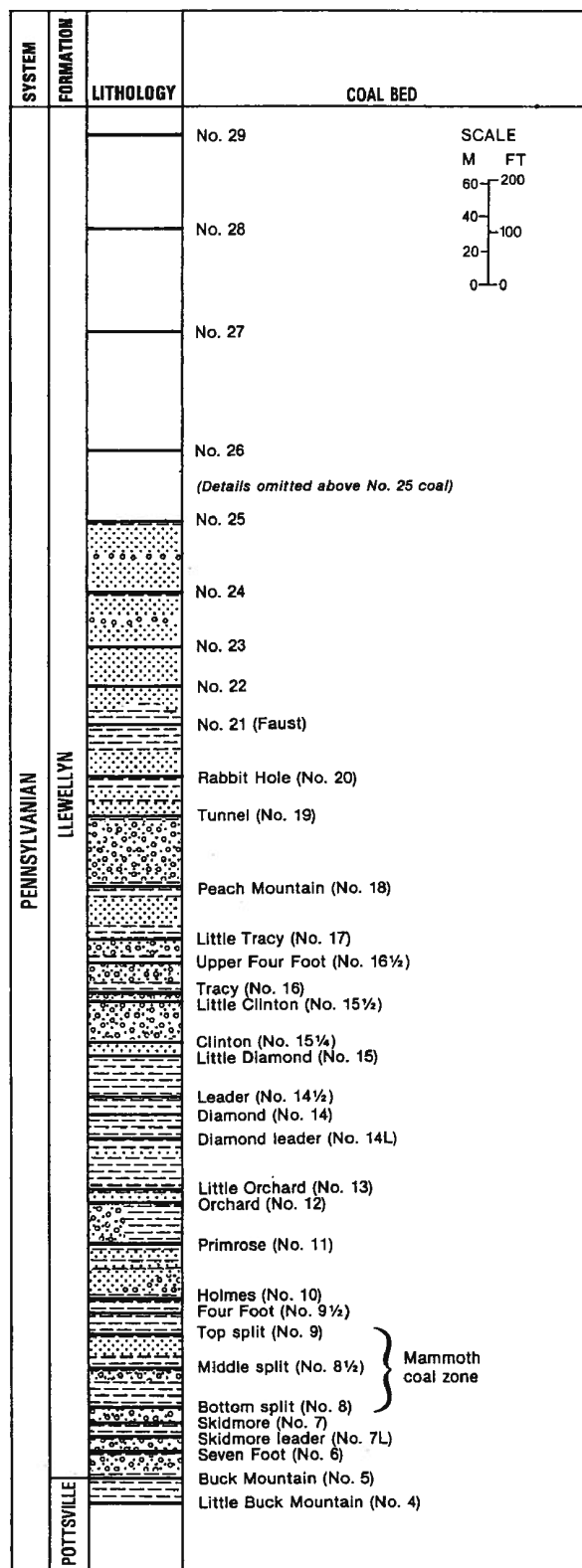
Palynological studies have been conducted on a number of specific Pennsylvanian beds, mostly in limit-

ed areas, but have not been integrated into a biostratigraphic system (Cross and Schemel, 1952; Clendening and Gillespie, 1964; Gray, 1965a, b; Habib, 1965, 1966; Groth, 1966). Paleobotanical and palynological problems associated with the placement of the Pennsylvanian-Permian boundary are discussed in Chapter 11.

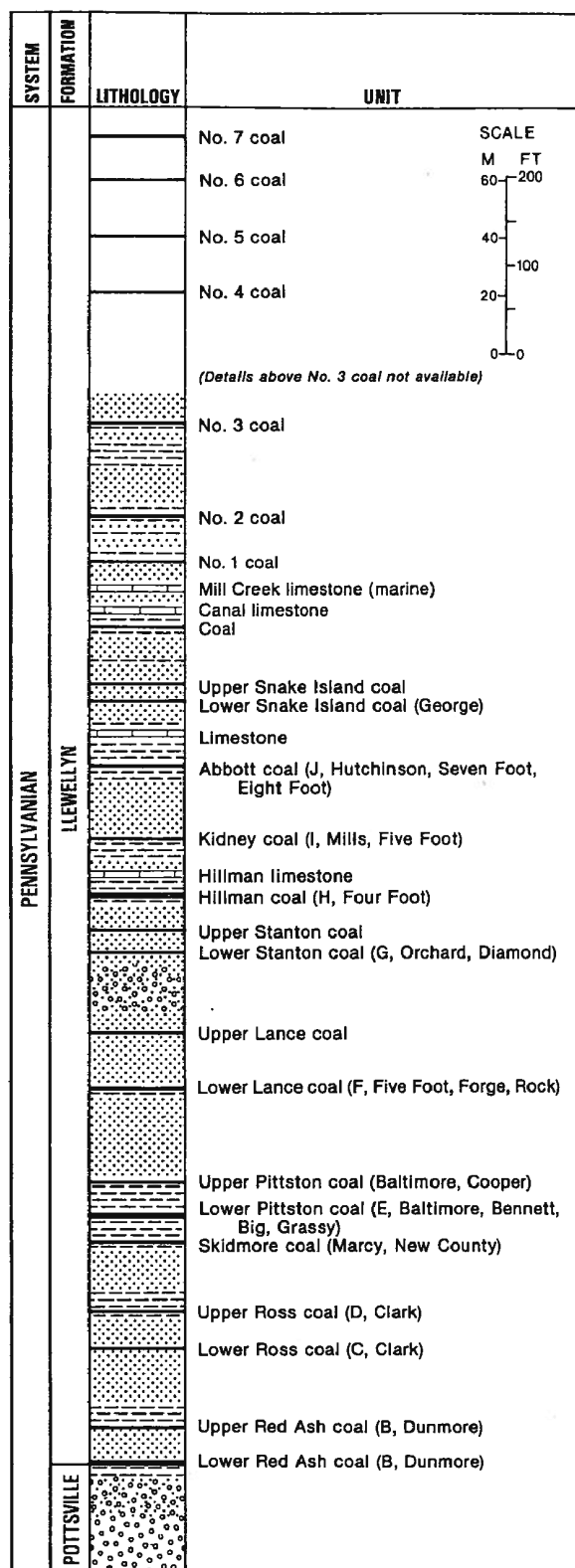
The distribution of fossil faunal assemblages within the Pennsylvanian System in Pennsylvania is strongly influenced by variations in depositional environments. Marine and marginal-marine forms are limited to two intervals in western and north-central Pennsylvania. The lower marine sequence extends from the Mercer shales and limestones of the Pottsville Formation to the Washingtonville shale of the Allegheny Formation (Figures 10-6



Figure 10-15. Basal conglomerate of the Sharp Mountain Member, disconformably overlying Mississippian strata along Interstate Route 84-380, 0.5 mile east of the Dunmore exit, Lackawanna County. The height of the roadcut is approximately 25 feet.



**Figure 10-16. Generalized stratigraphic section of the Llewellyn Formation of the Southern and Middle Anthracite fields (adapted from Arndt, 1963, Figure 3).**



**Figure 10-17. Generalized stratigraphic section of the Llewellyn Formation of the Northern Anthracite field.**



and 10–7). The upper marine interval extends from the Brush Creek marine zone (or possibly a Mahoning marine zone) in the lower Glenshaw Formation to the Skelley marine zone (Birmingham shale) in the lower Casselman Formation (Figure 10–8). Elements of this upper marine sequence occur in the Broad Top field (Edmunds and Glover, 1986), and one marine tongue reaches the Northern Anthracite field as the Mill Creek limestone in the Llewellyn Formation (Chow, 1951; Figure 10–17). Edmunds (1992) has demonstrated the presence of a marine fauna at the base of the Pottsville Formation in the southern Broad Top area. Potentially, nonmarine fauna should occur, at least intermittently, throughout the entire Pennsylvanian. Except for the comprehensive work of Williams (1960) on the macrofauna of the Allegheny Formation and the upper Pottsville Formation, most paleozoological studies have been narrowly limited with respect to stratigraphic interval, areal distribution, and faunal subject (Table 10–1).

Investigations by Shaak (1972), Donahue and Rollins (1974), Norton (1975), Rollins and Donahue (1975), Rollins and others (1979), Al-Qayim (1983), and Saltsman (1986) dealt with the relationships between marine ecosystems and their associated depositional environments for the various marine zones of the Glenshaw Formation. Studies have also been made of the relationship between the depositional setting of the Lower Kittanning coal (Allegheny Formation) and its petrography (Ting, 1967), its palynology (Habib, 1965, 1966), and the palynology of its overlying sediments (Groth, 1966).

## CHRONOSTRATIGRAPHY

The rock sequence spanning the Mississippian-Pennsylvanian time boundary is conformable only in the Southern and Middle Anthracite fields. At the type section of the Pottsville Formation (an exposure through Sharp Mountain a few miles south of Pottsville in the Southern Anthracite field), the systemic time boundary falls, by definition, at the same stratigraphic position as the base of the Pottsville (Figure 10–3). Because the Pottsville-Mauch Chunk contact is defined as the top of the highest red bed and the stratigraphic position of the highest red bed rises somewhat to the north, the systemic boundary passes into the upper Mauch Chunk Formation (Wood and others, 1969; Berg and others, 1986). Elsewhere in Pennsylvania, the systemic boundary occurs within a regional disconformity below the Pottsville.

Where marine beds are present, the upper Pottsville Formation, the Allegheny Formation, and the

**Table 10–1. Summary of Paleozoological Studies of Pennsylvanian Rocks in Pennsylvania**

<i>Northeastern Pennsylvania (Anthracite Area)</i>	
Pottsville and Llewellyn Formations	
Insects: Carpenter (1960, 1967)	
Llewellyn Formation	
Mill Creek marine macrofauna: Chow (1951); Ashburner (1886)	
<i>Western Pennsylvania (Bituminous Area)</i>	
Sub-Mercer Pottsville Formation: Edmunds (1992)	
Pottsville (upper part) and Allegheny Formations	
All macrofauna: Williams (1960)	
Fusulinids: Smyth (1974)	
Conodonts: Merrill (1970–71)	
Allegheny Formation	
Vanport Limestone cephalopods: Sturgeon (1964); Murphy (1966)	
Darlington (Lower Kittanning?) shale and Upper Freeport limestone vertebrates: Lund (1975)	
Columbiana shale macrofauna: Smith (1968)	
Glenshaw Formation	
Fusulinids: Smyth (1974)	
Conodonts: Merrill (1970–71)	
Brush Creek macrofauna: Seaman (1942); Donahue and others (1972); Shaak (1972); Brant (1971); see also Chow (1951)	
Brush Creek cephalopods: Murphy (1970)	
Brush Creek crinoids: Burke (1967, 1968)	
Brush Creek foraminifers: Norton (1975)	
Brush Creek gastropods: Knight (1941)	
Pine Creek (Cambridge) macrofauna: Seaman (1941); see also Chow (1951)	
Pine Creek (Cambridge) crinoids: Burke (1968)	
Ames macrofauna: Seaman (1940); see also Chow (1951)	
Ames crinoids: Burke (1968, 1970)	
Casselman Formation	
Skelley (Birmingham shale) macrofauna: Raymond (1911)	
Nonmarine bivalves: Eagar (1975)	
Vertebrates: Lund (1975)	
Monongahela Group	
Nonmarine bivalves: Eagar (1975)	
Vertebrates: Lund (1975)	

Glenshaw Formation of western Pennsylvania and adjacent Ohio are correlated with a good degree of accuracy to the marine beds present in the type areas of the late Atokan, Desmoinesian, and Missourian Stages of the mid-continent (Sturgeon and Hoare, 1968). The ages of the lower part of the Pottsville Formation, the Casselman Formation, the Monongahela Group, and the controversial Pennsylvanian-Permian boundary in western Pennsylvania (see Chapter 11 and Barlow and Burkhammer, 1975) are based mainly upon paleobotanical, including palynological, correlations that are less clear.

Except for the Missourian Mill Creek marine zone in the Northern Anthracite field, all time equivalences in the Anthracite region are derived from paleobotanical correlations. The Pottsville Formation of the Southern and Middle Anthracite fields spans Morrowan through early Desmoinesian Stages but internally seems to be missing the Atokan equivalents (see Read in Moore and others, 1944; Edmunds, 1988). In the Northern field, the Pottsville, including the Campbells Ledge shale, is latest Atokan through early Desmoinesian (White, 1900; Read in Moore and others, 1944; Edmunds, 1988).

Age correlation of the Llewellyn Formation is more controversial. All agree that the lower part of the formation is middle and late Desmoinesian, but Read (Read and Mamay, 1964; Wood and others, 1969, Table 1) extended the Missourian equivalent above the middle of the formation (to the Faust coal), whereas Darrah (1969), using European time terminology, appears to have placed the Missourian-Virgilian boundary about 600 feet lower (approximately at the Diamond coal) and considered the upper two thirds of the Llewellyn to be Virgilian, if not partly Permian. Eggleston and others (1988) concluded that the flora of the No. 25 coal, 500 feet above the Faust coal and several hundred feet below the top of the formation, was probably equivalent to part of the Monongahela Group and, therefore, Virgilian in age.

The Pennsylvanian sequence of the Broad Top field in south-central Pennsylvania contains two or three marine zones that are believed to be equivalent to some of the Glenshaw marine zones of western Pennsylvania (Edmunds and Glover, 1986) and, therefore, are Missourian in age. The highest marine zone is at least 250 feet below the top of the section, presumably leaving room for some equivalent of the Virgilian Casselman Formation. Fossil lists (Gardner, 1913) suggest that most or all Desmoinesian-equivalent strata are present, but the maximum age beyond that is unclear. The use of marine invertebrates, macroflora, and microflora has permitted dating of the base of the Pottsville Formation in the southern Broad Top area as middle Morrowan (Edmunds, 1992).

Very little work has been done on the biostratigraphy of the 300-foot Pennsylvanian section of the North-Central fields. The presence of marginal-marine faunal zones suggests equivalency to some part of the upper Pottsville Formation to lower Allegheny Formation of western Pennsylvania and, therefore, a late Atokan to early Desmoinesian age. White (1904), Read (1946), and Pfefferkorn (personal communication, 1977) indicated that the fossil flora at

and near the Bloss (B) coal near the middle of the sequence is also equivalent to the upper Pottsville Formation to lower Allegheny Formation.

## DEPOSITIONAL HISTORY

The Mississippian-Pennsylvanian contact is conformable only in the area of the Southern and Middle Anthracite fields in east-central Pennsylvania. Elsewhere in the state, the earliest Pennsylvanian rocks, as well as some or all of the Late Mississippian sequence, are unconformably missing. Englund (1979) has dated the onset of erosion associated with the unconformity in the central Appalachians as early Morrowan. This erosion followed deposition of earliest Morrowan sediments approximately equivalent to the lower two thirds of the Tumbling Run Member of the Pottsville Formation (Figure 10-18A).

The original extent of Late Mississippian (Chesterian) and very earliest Pennsylvanian rocks prior to the onset of erosion cannot be demonstrated directly within Pennsylvania. Since, however, it can be shown that the immediately preceding late Meramecian age Loyalhanna Member of the Mauch Chunk Formation extends across most of the state and that deposition of the Chesterian-earliest Morrowan sequence is continuous in east-central Pennsylvania and also in western Virginia and southern West Virginia, it is most likely that continuous Chesterian and earliest Morrowan rocks originally extended across all of Pennsylvania (except the source area in the southeast), and also westward into Ohio and northward into New York.

The early Morrowan erosion surface encompassed all of western and central Pennsylvania, but it did not extend into the east-central part of the state, where deposition was continuous (Figure 10-3). Whether or not the erosion surface extended into northeastern Pennsylvania in the area of the Northern Anthracite field cannot be determined, as that part of the section has been removed by a still later erosion surface.

The development of the early Morrowan erosion surface has been explained as the product of either structural arching of the area or eustatic sea-level decline. White (1904) proposed widespread epeirogenic uplift. Eustatic drop in sea level at the time of the Mississippian-Pennsylvanian boundary was considered to be a potential cause by Swann (1964) and Saunders and Ramsbottom (1986). Ettensohn and Chesnut (1989) observed that the onset of erosion in the central Appalachians occurred later than the Mis-



Mississippian-Pennsylvanian boundary sea-level fall and concluded that the erosion surface was primarily the result of the rise of a peripheral tectonic bulge with, possibly, some subordinate influence from sea-level change.

In east-central and, possibly, northeastern Pennsylvania, where sedimentation was continuous, very coarse alluvial clastics built out from the southeastern orogenic highlands across the upper surface of the alluvial red beds of the Mauch Chunk Formation (Figure 10-18A) (Meckel, 1964, 1967; Wood and others, 1969). During middle and late Morrowan, interfluvial peat swamps developed in the more southerly part of the alluvial plain. Wet tropical conditions had clearly replaced the semiarid, seasonal wet-dry climate of Late Mississippian time.

Marine conditions briefly encroached across the erosion surface in south-central Pennsylvania in middle Morrowan time, followed by prograding alluvial coarse clastics (Edmunds, 1992).

A high-energy fluvial system, originating in New York, flowed southwestward across the northwest corner of the state, carrying the coarse clastics of the Sharon (Olean) conglomerates and sandstones into eastern Ohio and beyond (Figure 10-18B) (Fuller, 1955; Meckel, 1964; Rice and Schwietering, 1988). The Sharon fluvial system is at least as old as late Morrowan, based upon the flora of the overlying Sharon coal bed and shales, but was probably present as early as middle Morrowan.

The erosion surface in the rest of western Pennsylvania consisted of northern and southern positive areas separated by a higher west-east cuesta corresponding to the outcrop of the resistant Lower Mississippian Burgoon Sandstone.

In early and middle Atokan, coarse clastics of the Connoquenessing sandstones and finer grained equivalents buried the erosion surface in western and central Pennsylvania except for a narrow remnant of the Burgoon cuesta (Figure 10-18C).

At some time during the Atokan, the area of the Northern Anthracite field was uplifted and eroded down to Mississippian and uppermost Devonian rocks (Figure 10-18C). Read (Moore and others, 1944) and Edmunds (1988) concluded that this disconformity extends throughout the other anthracite fields, where it separates the Sharp Mountain Member from the lower members of the Pottsville Formation. Inners (1988) similarly concluded that this disconformity is present in the other anthracite fields, but below the Schuylkill Member. Meckel (1964) and Wood

and others (1969) rejected the presence of this disconformity outside the Northern Anthracite field.

Commencing in latest Atokan and continuing through the first half of Desmoinesian time, a general eastward shift of marine conditions introduced a series of shallow-marine transgressions into western Pennsylvania, resulting in deposition of the Mercer shales and limestones of the upper Pottsville Formation upward through the Washingtonville shale of the middle Allegheny Formation (Figure 10-18D through 10-18F). Depositional environments included a shallow-marine shelf, marine carbonate banks, coastal marshes and swamps, lagoons, and distributary deltas, which grade into alluvial-plain fluvial distributaries and interdistributary flood basins (Ferm, 1962, 1970, 1974, 1975; Williams and Ferm, 1964; Ferm and Williams, 1965; Weber and others, 1965; Ferm and Cavaroc, 1969; Williams and Bragonier, 1974; Cavaroc and Saxena, 1979).

Beginning at the same time as, or shortly after, deposition of the Mercer units in the west, a major incursion of very coarse alluvial clastics spread across northeastern Pennsylvania, which formed the conglomerates and sandstones of the Sharp Mountain Member of the Pottsville Formation. Beginning with the Llewellyn Formation in middle Desmoinesian time, the alluvial sediments of northeastern Pennsylvania became distinctly less coarse and included many widespread peat swamps (Wood and others, 1969). With one notable exception, a marine transgression discussed below, the depositional environment in the northeast remained basically unchanged throughout the remainder of the Pennsylvanian Period (Figure 10-18F through 10-18J).

During late Desmoinesian time, marine conditions withdrew westward into Ohio. The depositional environment in western Pennsylvania (Figure 10-18G) became entirely that of an alluvial plain with complex fluvial channels, large, isolated coal swamps, and freshwater lakes (Pedlow, 1977; Sholes and others, 1979; Skema and others, 1982). Rocks within the stratigraphic interval from the Johnstown limestone of the Allegheny Formation up through the Brush Creek coal of the Glenshaw Formation were the product of this deposition. Except for the discovery of a few brackish-water fossils above the Mahoning coal in two cored holes drilled in Somerset County in 1981 and Westmoreland County in 1990, there are no known marine units in this interval in Pennsylvania.

The Missourian and possibly very earliest Virgilian rocks from the Brush Creek marine zone of

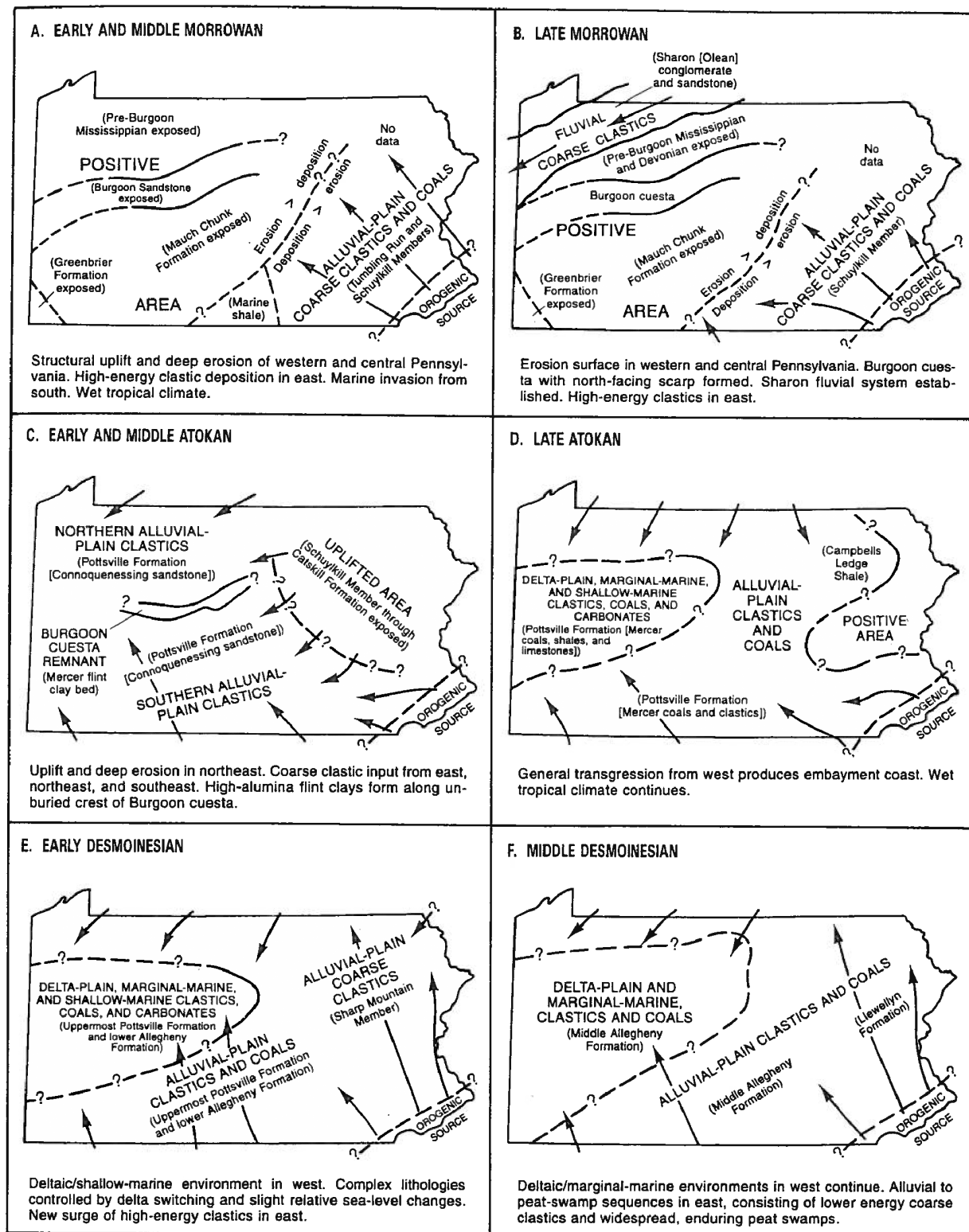


Figure 10-18. Pennsylvanian paleogeography and depositional environments (modified from Edmunds and others, 1979).

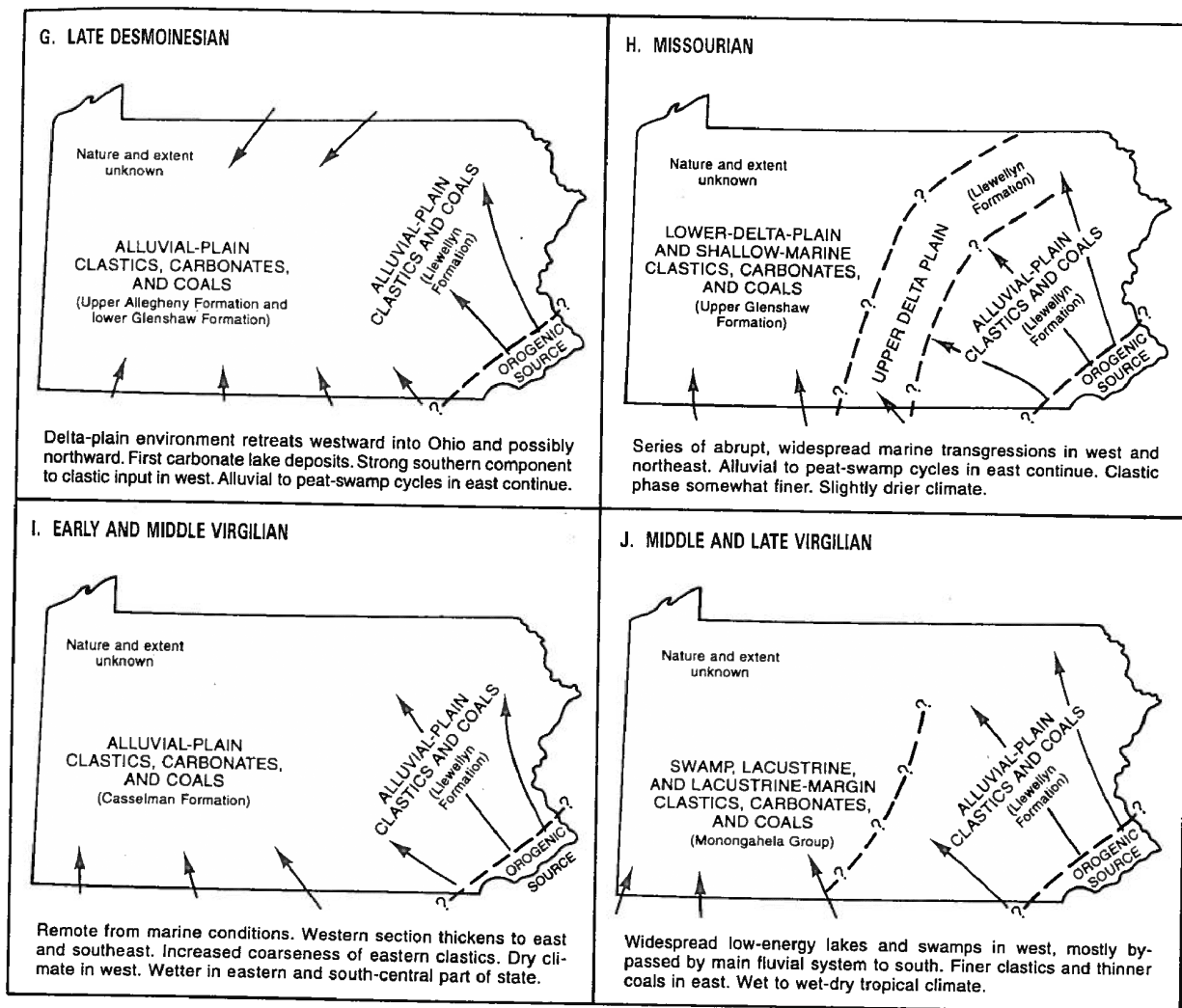


Figure 10-18. (Continued).

the Glenshaw Formation to the Skelley marine zone of the Casselman Formation are characterized by a series of sharp eastward marine transgressions (Figure 10-18H), which resulted in the establishment of shallow-marine, coastal-plain, and lower-delta-plain conditions across all of western Pennsylvania (Morris, 1967; Donahue and Rollins, 1974; Al-Qayim, 1983; Saltsman, 1986). Busch and Rollins (1984) described seven distinct marine transgressions (including the Mahoning event) in the Glenshaw Formation, which they ascribed to eustatic sea-level changes. There is, in addition, the eighth, and last, Skelley marine transgression in the lowest part of the Casselman Formation. Interspersed between the shallow-marine limestones and black shales are low-

energy, delta-plain distributary sediments, coastal-plain coals, freshwater limestones, and caliche-bearing red-bed paleosols. One marine transgression (commonly assumed to be Ames equivalent) reached as far east as the Northern Anthracite field, where the Mill Creek sideritic limestone is clearly a shallow-marine deposit and other beds for at least several tens of feet above and below the Mill Creek have sedimentary characteristics distinctly unlike the usual alluvial features of the Llewellyn Formation. In addition, the presence of nonmarine limestones in the 330-foot interval below the Mill Creek suggests a possible distal-alluvial-plain environment.

Near the beginning of the Virgilian Stage, marine conditions withdrew permanently from Pennsyl-

vania (Figure 10-18I). Although there have been no systematic studies of the depositional setting of the early Virgilian Casselman Formation, the presence of freshwater limestones, discontinuous coals, and red beds suggests a relatively drier alluvial-plain setting. Any marine connection is very remote.

By the last half of Virgilian time, represented by the Monongahela Group, the northeastern end of the Appalachian basin was almost completely severed from any marine connection (Figure 10-18J). The main sediment input at this time was farther south across West Virginia, and there were only intermittent diversions northward into Pennsylvania. Sediment was also received from secondary sources to the north. The general environment appears to have been that of an isolated, relatively low-energy alluvial plain containing widespread coal swamps and freshwater lakes (Donaldson, 1969, 1974, 1979; Berryhill and others, 1971; Marrs, 1981). The Pittsburgh coal swamp apparently extended across all of southwestern Pennsylvania, but other coal swamps were more limited. Most of the late Virgilian sequence consists of thick deposits of interbedded limestone and calcareous claystone that were laid down in freshwater lakes. The sequence was terminated by a renewed influx of clastics.

## DEPOSITIONAL CONTROLS

Geologists have long speculated upon the nature of the depositional environments and the factors operating thereon that have produced the complex Pennsylvanian sequence with its multiplicity of thin, interbedded lithologies. From the beginning, it was recognized that, in a general way, the rocks represented some sort of subtropical coastal lowland setting in which alluvial elements that emanated from the east interfaced with marine or lacustrine conditions to the west. Determining the degree of continuity of individual lithosomes has always been a particularly difficult problem. This question of lithologic persistence is important, not only from the abstract sedimentological standpoint, but also in matters of stratigraphic subdivision or correlation and the economic geology of the coal beds. For whatever reason, the concept that individual units have great lateral persistence steadily gained acceptance. By the time of the Second Pennsylvania Geological Survey (Lesley, 1879), certain sandstones and most coal beds were treated as widespread sheets and were made the official boundaries of all major stratigraphic subdivisions.

The cyclothem concept (i.e., the idea that thin, repetitive, laterally persistent lithologies reflect the effects of external (allocyclic) processes operating basin-wide) promised to provide the theoretical underpinning for the notion of widespread lithosome continuity. Decades were spent trying to fashion a representative Appalachian cyclothem or cyclothem (Reger, 1931; Stout, 1931; Cross and Arkle, 1952; Sturgeon, 1958; Beerbower, 1961; Branson, 1962). Eventually, it became apparent that no reasonable number of representative cyclothem could be devised that would hold up for any distance, laterally or vertically. Although it is usually not difficult to recognize cyclic alternations between low-energy sediments (such as peat) at one extreme and high-energy sediments (such as fluvial sandstone or conglomerate) at the other, the character, order, and extent of individual lithosomes are too variable to reduce to any simple order regulated by allocyclic controls alone.

Comparison of modern sedimentary systems and the internal (autocyclic) processes that control the nature and distribution of individual modern lithosomes with their ancient analogues has permitted interpretation of much of the complex lithologic variation encountered in the Pennsylvanian sequence (Donaldson, 1969, 1974, 1979; Ferm and Cavaroc, 1969; Ferm, 1970, 1979a, 1979b).

In spite of the success achieved in applying autocyclic depositional concepts, many of the broader aspects of the Pennsylvanian rocks have such general and wide-ranging influence that allocyclic factors must be at work as well. Without referring to specific lithologies, Busch and Rollins (1984) and Heckel (1986) reiterated the point that it is possible to recognize the effects of widespread transgressive-regressive couplets, at least in those parts of the section that include marine units. During the Pennsylvanian, the tropical climate of Pennsylvania ranged between persistently wet and semiarid seasonal wet-dry conditions. The pronounced depositional effects of these variations have been emphasized by Phillips and Peppers (1984), Cecil and others (1985), Donaldson and others (1985), Cecil (1990), and Winston (1990).

Williams and Holbrook (1985), remarking on the apparent very large discrepancy between the estimated 20,000 to 40,000 years needed to produce the rock sequence from one prominent coal zone to the next, and the average of 400,000 years this same interval would represent if all such intervals are distributed throughout the total time available, concluded that most of the missing time is incorporated

in widespread erosional-surface paraconformities (see also Williams and others, 1965).

It appears, in fact, that both allocyclic and autocyclic controls were operating to a significant degree. These can be summarized as follows:

#### *Allocyclic Controls*

Geographic configuration of the basin  
Tectonic or epeirogenic activity in the source area  
Climatic changes  
Eustatic sea-level changes  
Differential subsidence and tectonic or epeirogenic activity within the basin

#### *Autocyclic Controls*

Sedimentary prograding  
Delta and distributary switching  
Alluvial-channel relocation  
Channel, levee, and flood-basin (constructive) fluvial processes  
Longshore coastal processes  
Physical and chemical impact of large-scale plant development  
Differential compaction

At any time and place, all of the above influences could have operated to some degree. When dealing with any particular aspect of the rocks in any selected interval and area, one must consider the *relative* influence of each of these controls.

## PROBLEMS AND FUTURE RESEARCH

Research in the following areas is needed in order to gain a better understanding of the geology of the Pennsylvanian in the Commonwealth and to develop a more applicable model of Pennsylvanian stratigraphy.

*Regional stratigraphic framework*—Much of the stratigraphy currently in use was established at a time when some sandstones and most coals were erroneously considered to have great lateral persistence. It is now known that the areal extent of these beds varies enormously and that many are not nearly as widespread as first thought. The identification of the regionally persistent lithosomes and an accurate assessment of their distribution are needed in order to correct the stratigraphic errors present in the literature. This is especially true in the parts of the Pennsylvanian that lack economically important units and

consequently have been mostly ignored, such as the Casselman Formation.

*Regional biostratigraphy*—Many of the paleontological studies of the Pennsylvanian have been narrowly limited in scope. Much of the past work has concentrated on the fauna of the open-marine beds of the Glenshaw Formation and the Vanport Limestone of the Allegheny Formation. Studies of the more restricted marine and brackish beds present throughout the upper Pottsville Formation, the lower Allegheny Formation, and the Glenshaw Formation, and an attempt to link these to their better-known marine equivalents in Ohio, would greatly improve our understanding of biostratigraphy in the Pennsylvanian. This is especially true in the much-neglected North-Central fields. Paleobotanical correlations, although extensive, are still relatively vague in relation to the present understanding of lithostratigraphy. Floral zonation is almost the sole source of correlation between the anthracite fields and western Pennsylvania and needs further clarification and refinement. Palynological zonation of the Pottsville Formation of western Pennsylvania should help to resolve age, correlation, and depositional-history problems associated with this relatively thin, but apparently long-enduring, high-energy clastic unit.

*Basal Pennsylvanian unconformity*—More work is needed regarding the cause of the unconformity below the Pennsylvanian sequence in western Pennsylvania, in particular, whether it represents the development of a tectonic arch (peripheral bulge), the effects of eustatic sea-level decline, or some combination thereof. The question also remains as to why the overlying Pottsville Formation of this area is only a few hundred feet thick while more than 2,000 feet of presumably laterally equivalent rocks were deposited above the same unconformity farther south in the central Appalachians.

*Paleoenvironmental reconstruction*—Further research is necessary on the paleoenvironments present at the time of Pennsylvanian deposition, including the nature and relative impact of the various controlling allocyclic and autocyclic processes. Accurate paleoenvironmental models would provide a more rational basis for developing a workable new stratigraphic framework. This is especially needed in the anthracite fields. A more thorough understanding of the depositional environment and climate in this region will aid in correlating these coals and their associated rocks, which have undergone extensive structural deformation. The areas of the Casselman and Pottsville

Formations of the bituminous fields are also in need of this type of approach.

*Existence, scale, and effects of intermittent widespread disconformities*—It has been claimed, with considerable theoretical justification, that the amount of real time represented by the present Pennsylvanian stratigraphic sequence falls far short of the actual amount of time spanned by the Pennsylvanian Period, and that most of Pennsylvanian time may be tied up in frequent, widespread intervals of nondeposition and/or erosion. The existence, areal extent, temporal duration, erosional results, and soil development of such disconformities should be investigated further because, if present, their effect upon stratigraphic and depositional concepts could be profound.

## RECOMMENDED FOR FURTHER READING

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